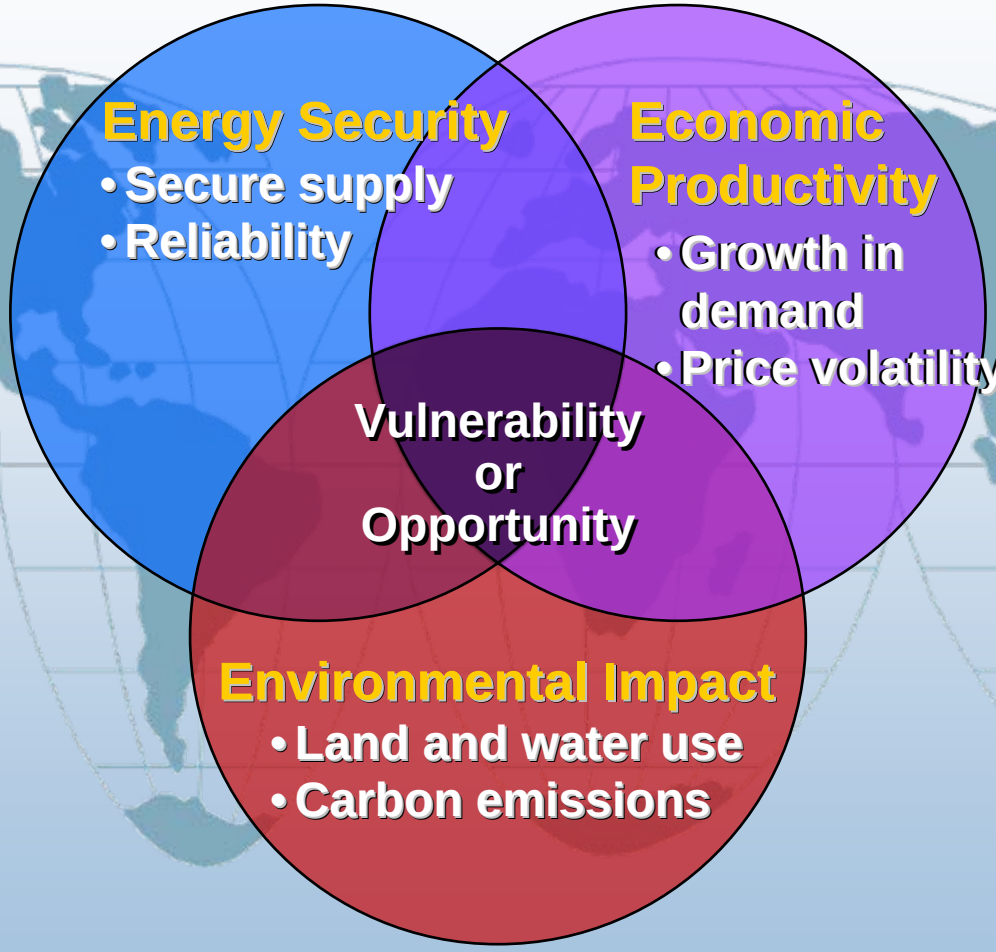
The Growing Significance of Renewable Energy

Great Plains Energy Expo

October 29, 2007

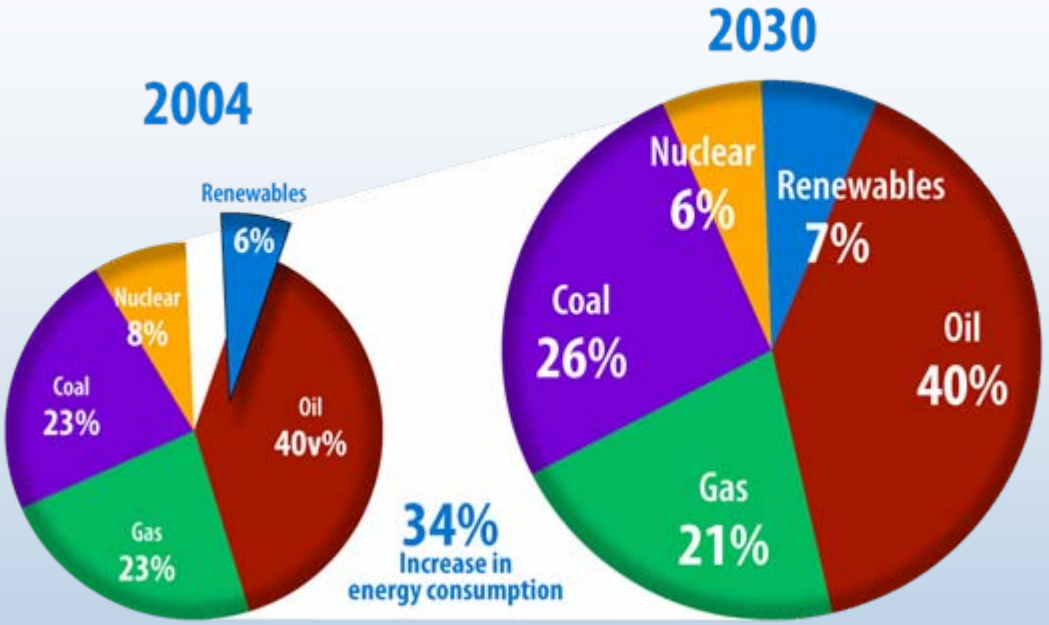
Dan E. Arvizu
Director, National Renewable Energy Laboratory

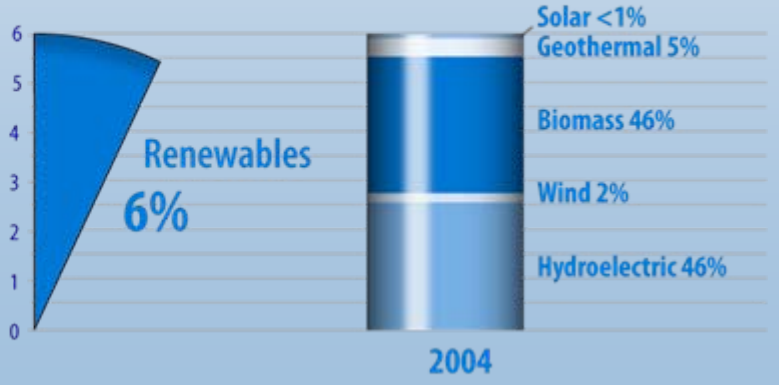
Energy Solutions Are Enormously Challenging



Must address all three imperatives

U.S. Energy Consumption and the Role of Renewable Energy

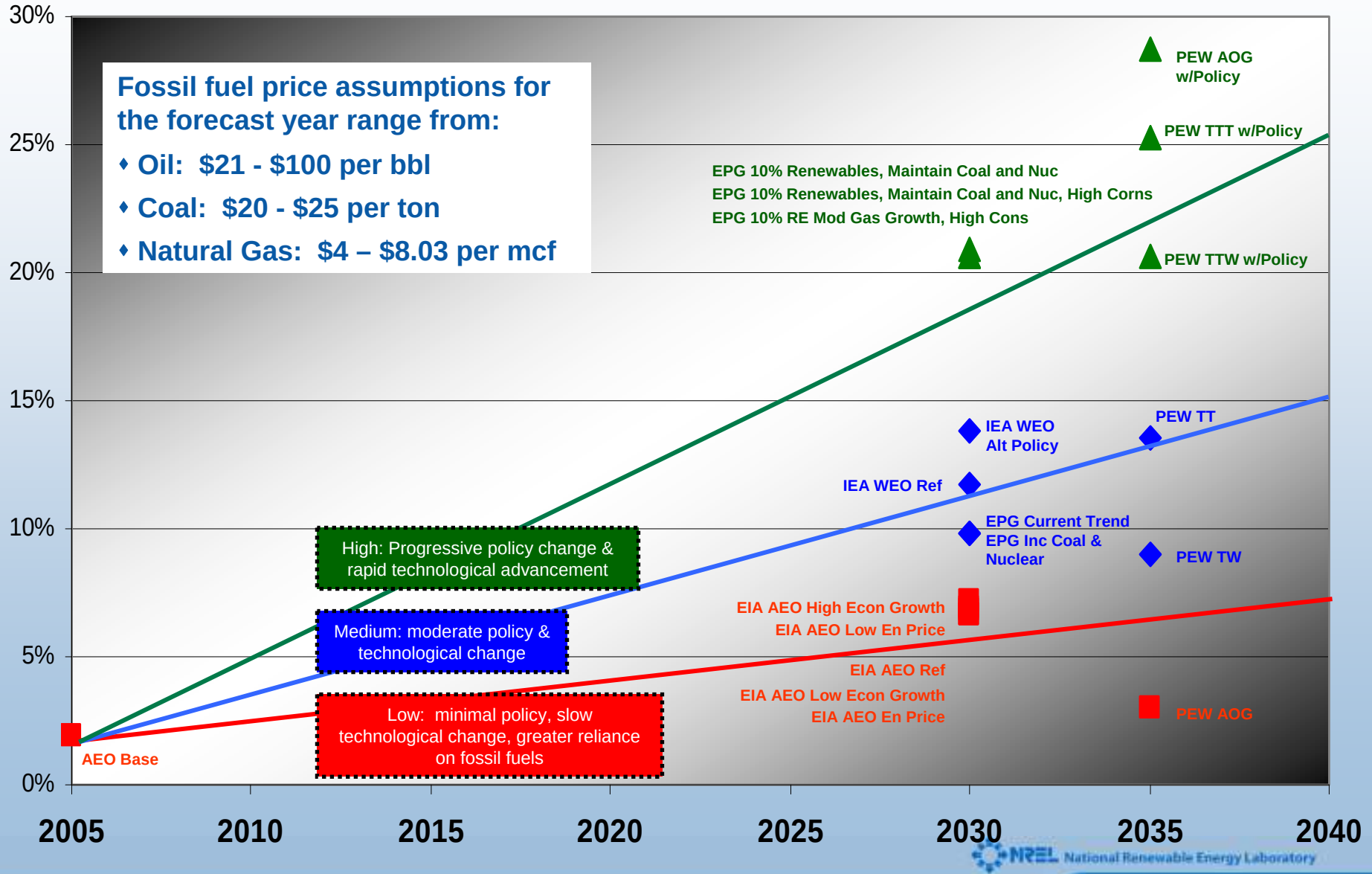




Source: Energy Information Administration, *Annual Energy Outlook 2006,* Table D4

U.S. Renewable Energy Contributions

Percent of Total Electric Generating Capacity



We Are Now Setting Aspirational Goals – Setting the Bar Higher

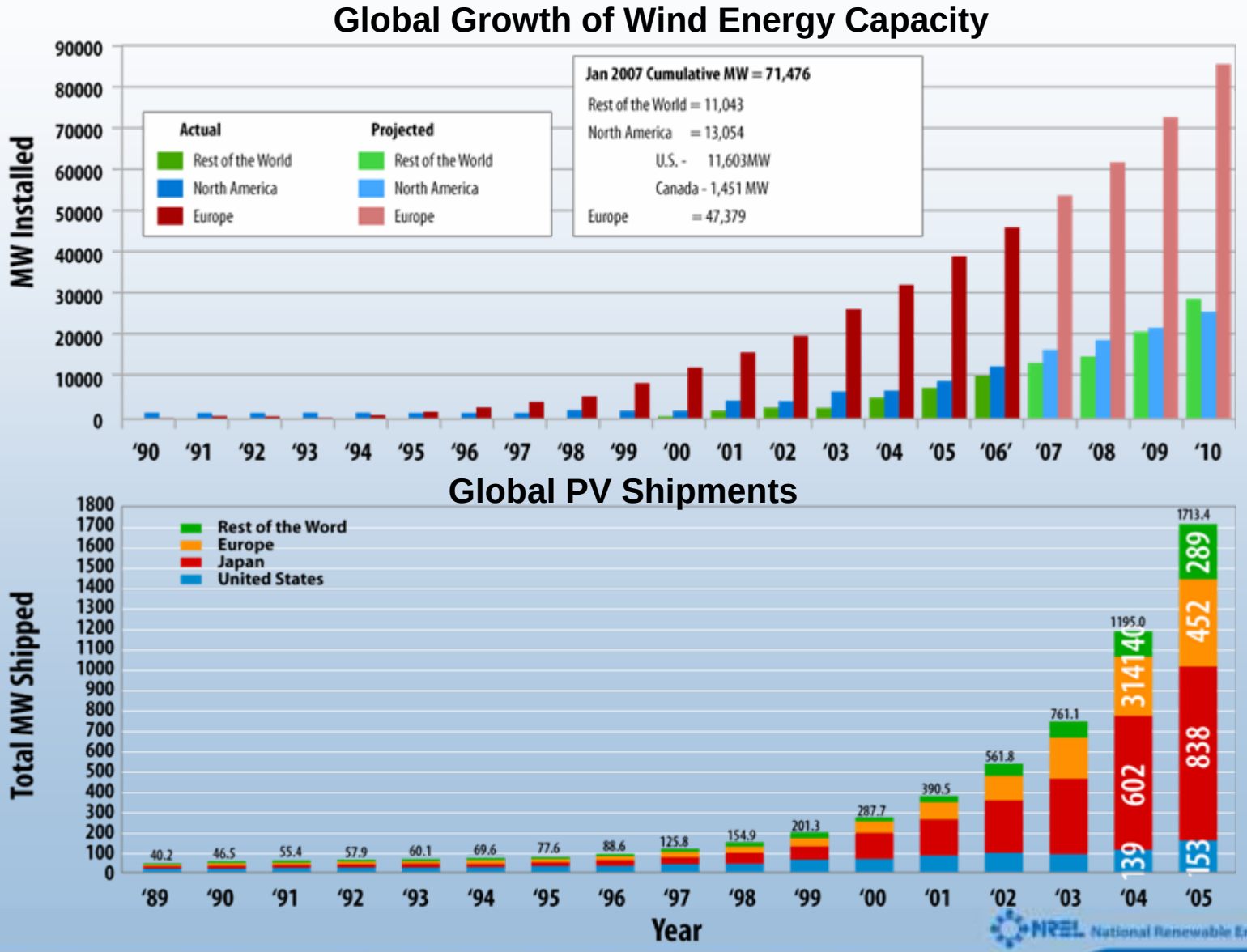
U.S. national goals

- Biofuels: reduce gasoline usage by 20% in ten years
- Wind: 20% of total provided energy by 2030
- Solar: Be market competitive by 2015 for PV and 2020 for CSP

Getting to “Significance” Involves…

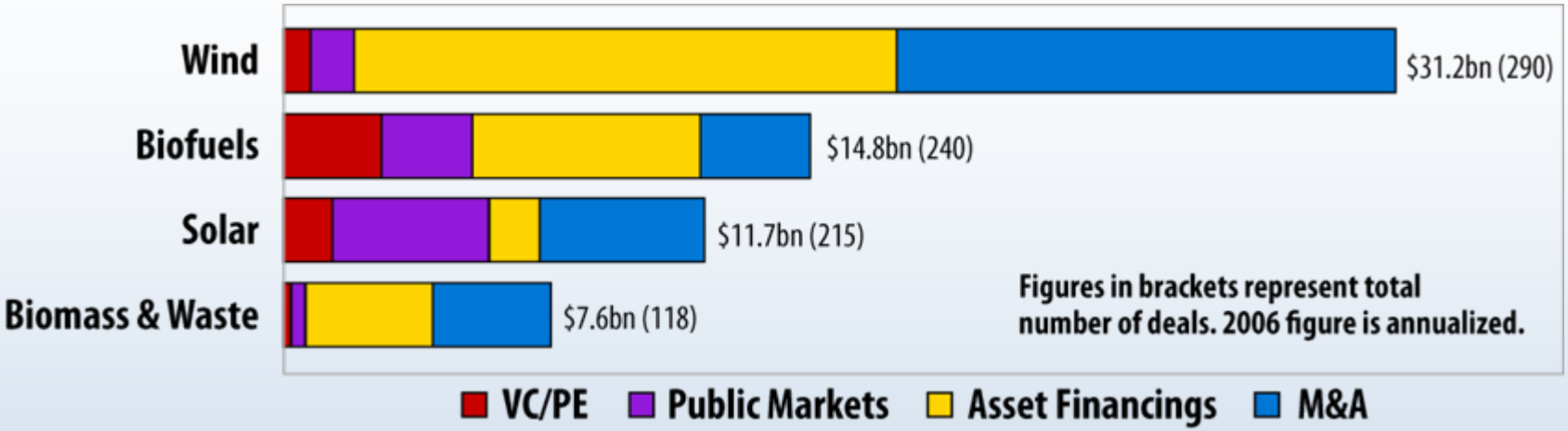
Source: NREL

Global Markets are Growing Rapidly

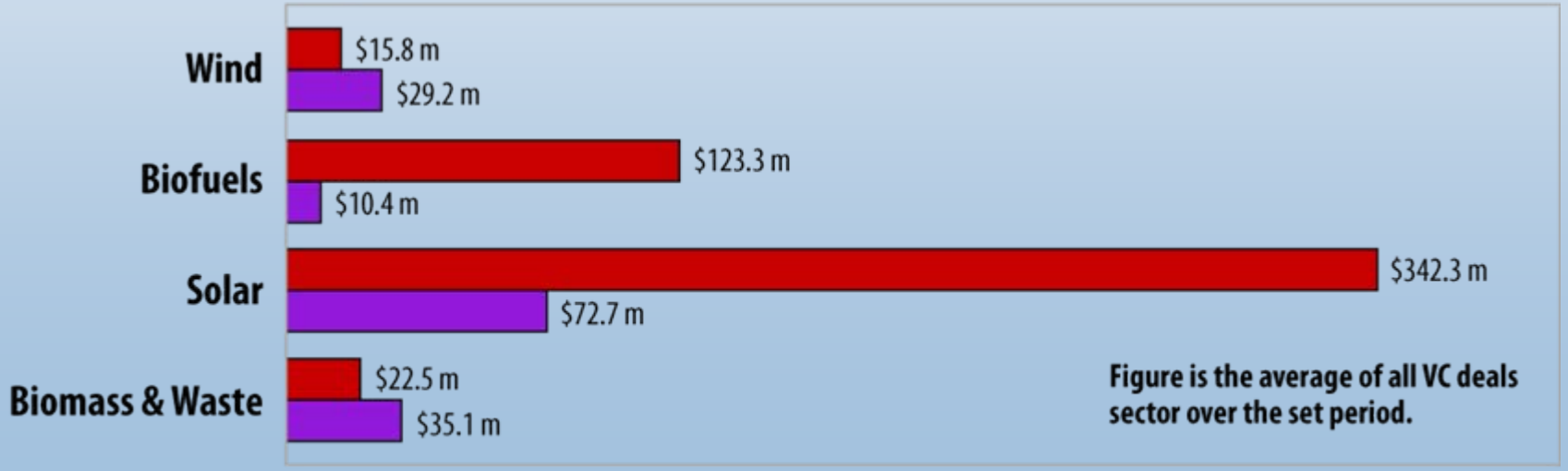


Money Is Flowing Into the Sector

2006 Investment and M&A – By Sector and Asset Class

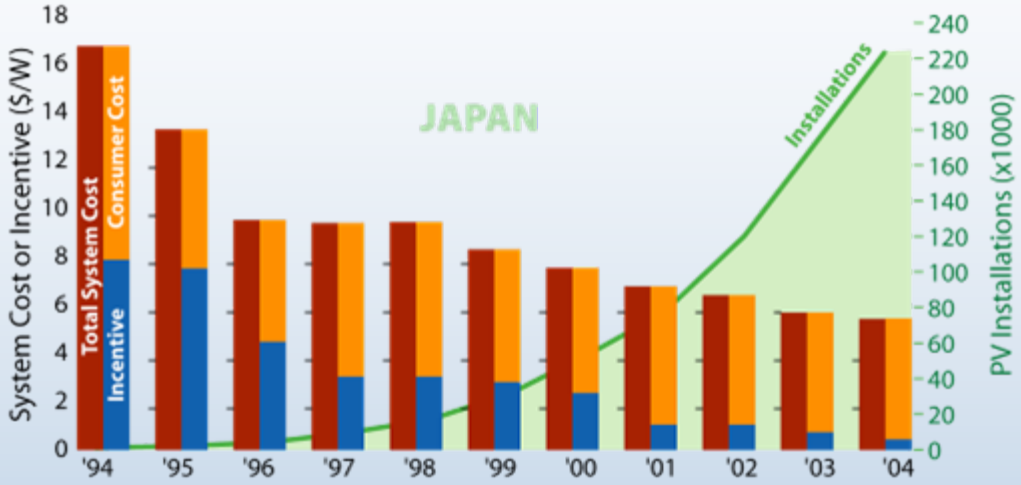


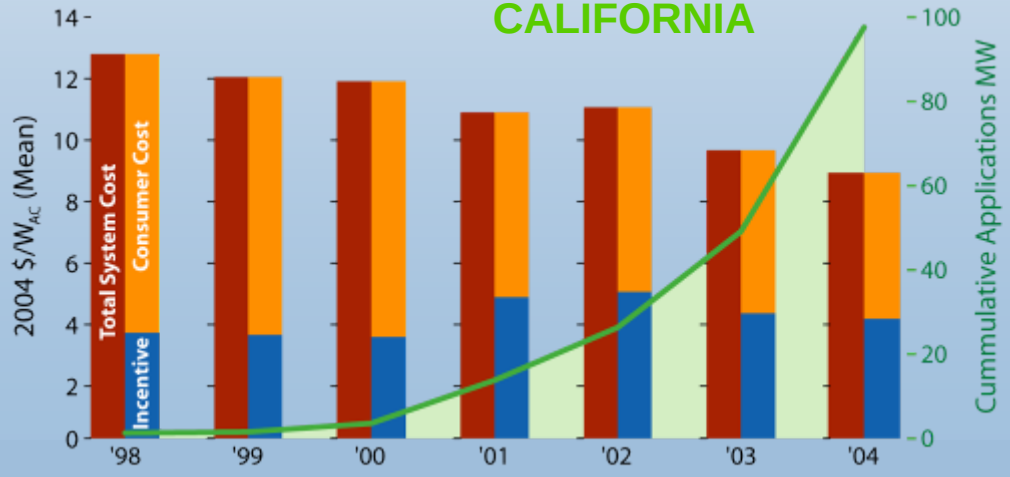
Annual VC Investment Volume – 2001-2004 Compared With 2005-2006

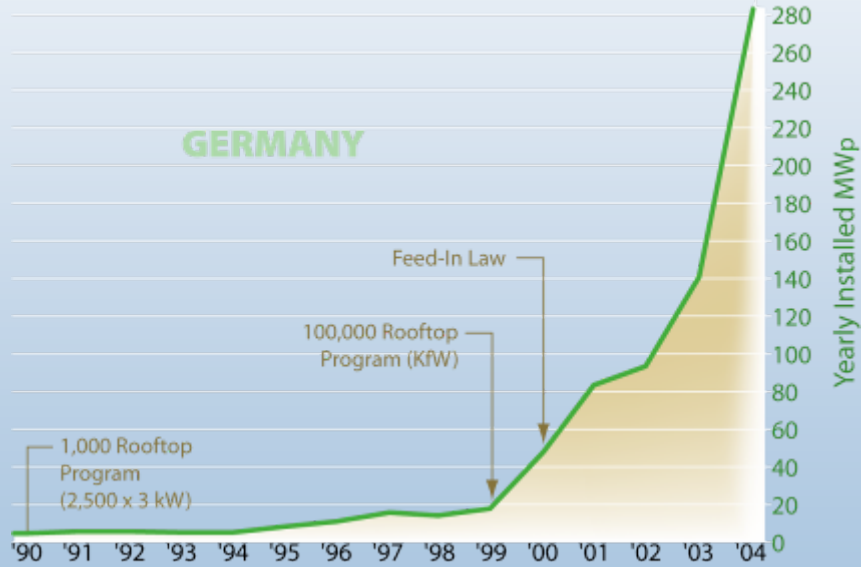


Source: New Energy Finance 2007

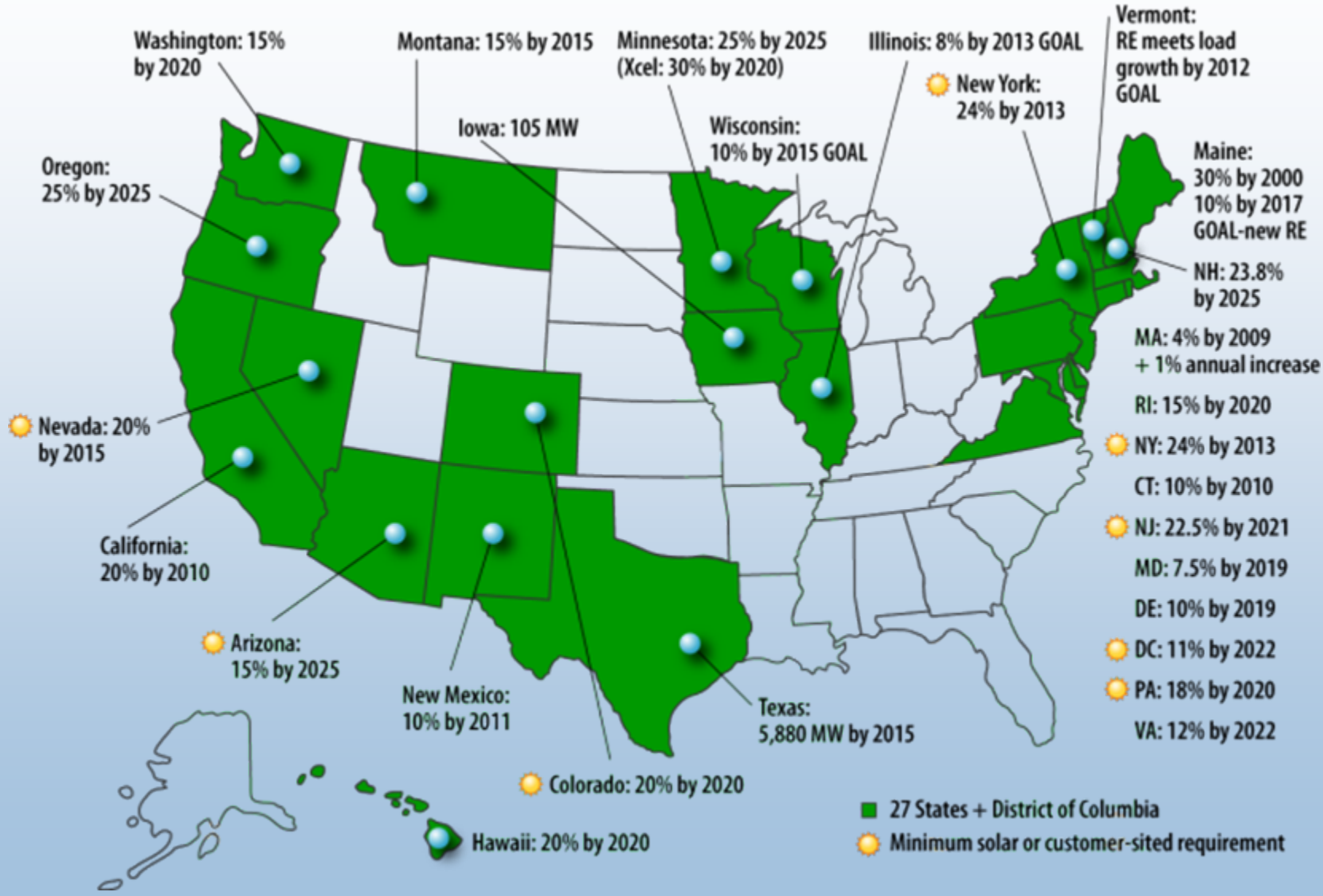
Worldwide Markets Have Driven Cost Reductions – Solar PV Example







State Policy Framework
Renewable Electricity Standards



Source: DSIRE database, July 2007

Energy Efficiency and Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

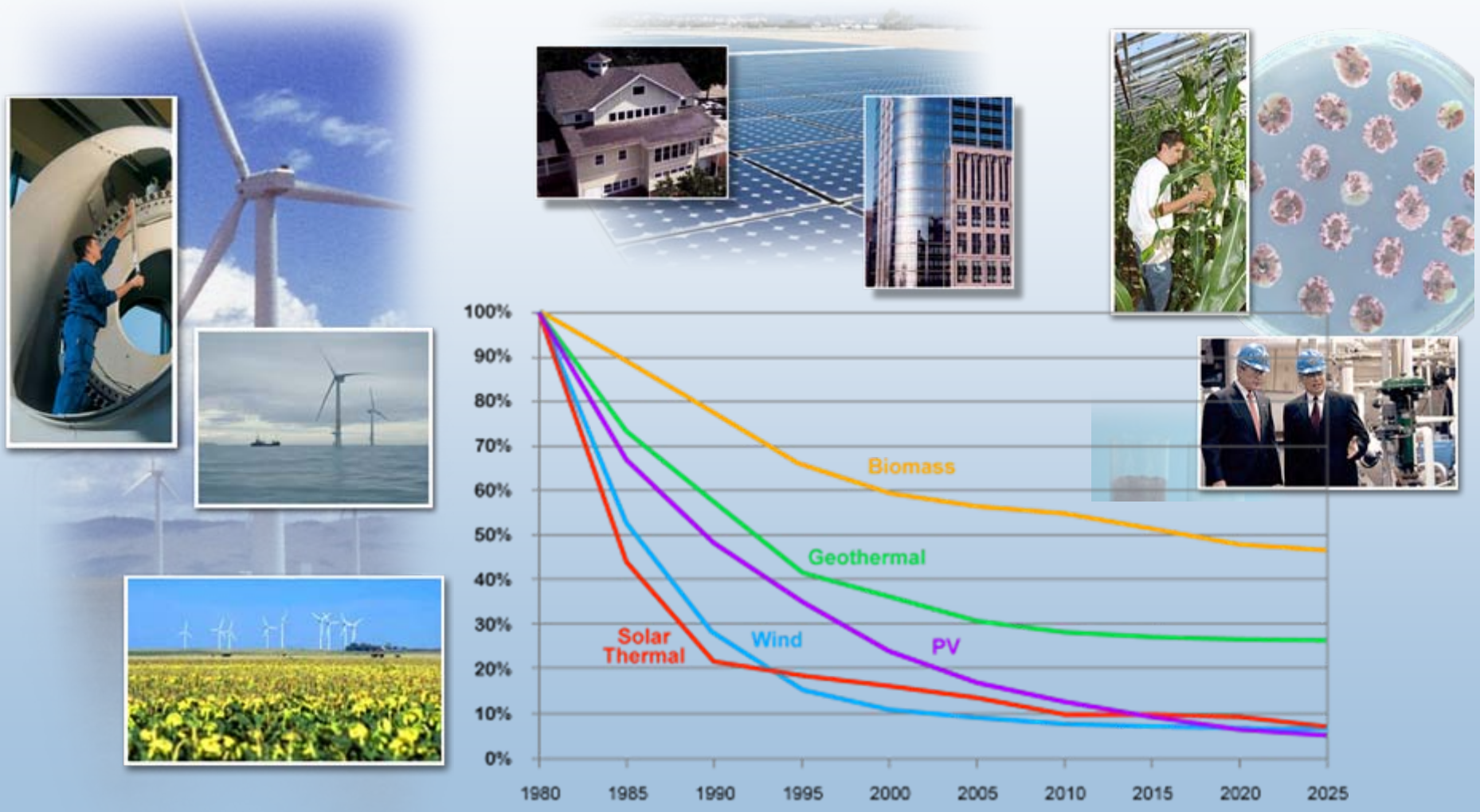
- Wind
- Solar
- Biomass
- Geothermal

Energy Delivery and Storage

- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

Foundational Science and Strategic Analysis

Past Investments Have Yielded Impressive Cost Reductions



Wind

Today's Status in U.S.

- 11,603 MW installed at end of 2006
- Cost 6-9¢/kWh at good wind sites*

DOE Cost Goals

- 3.6¢/kWh, onshore at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014

Long Term Potential

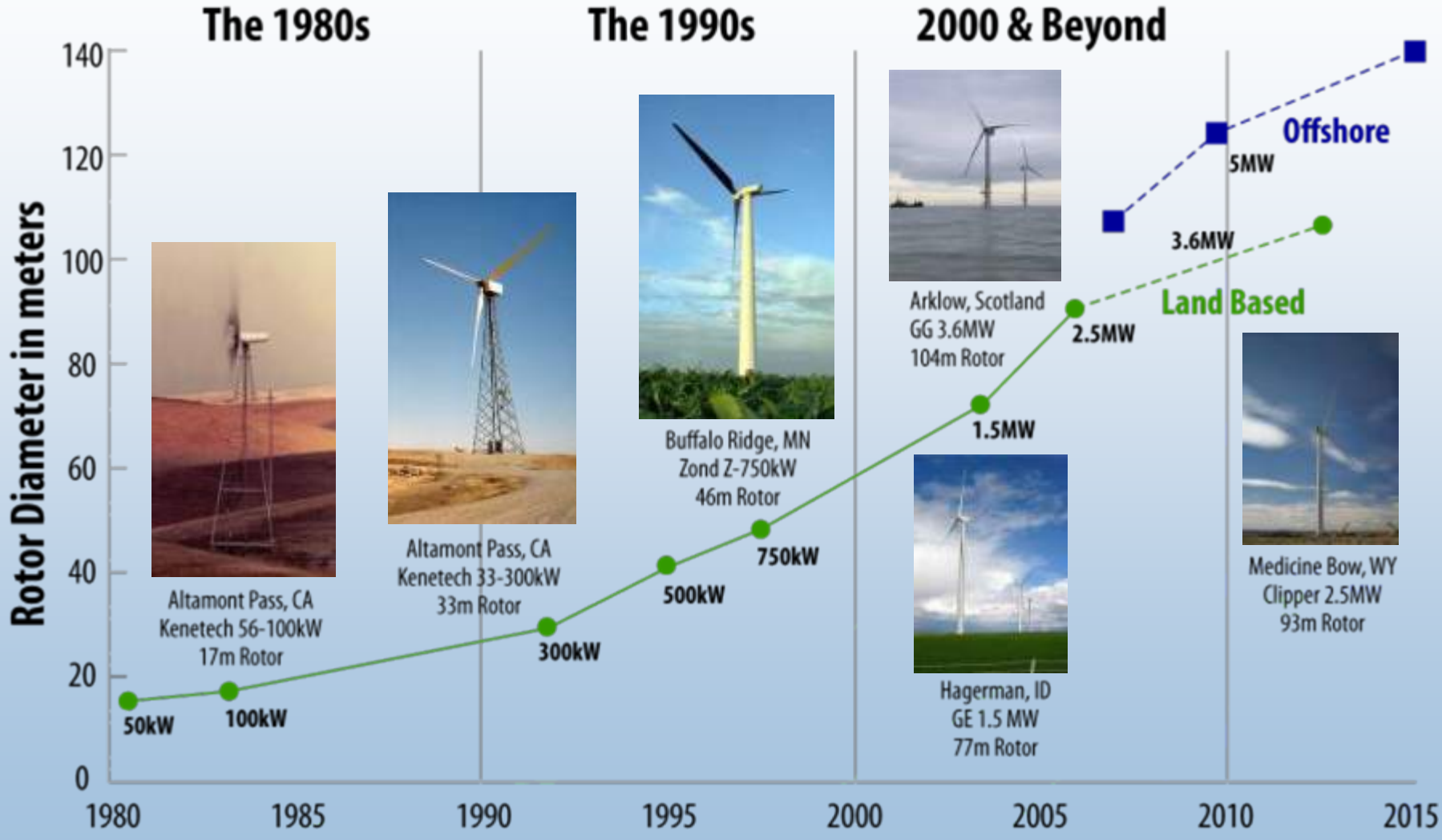
- 20% of the nation's electricity supply

NREL Research Thrusts

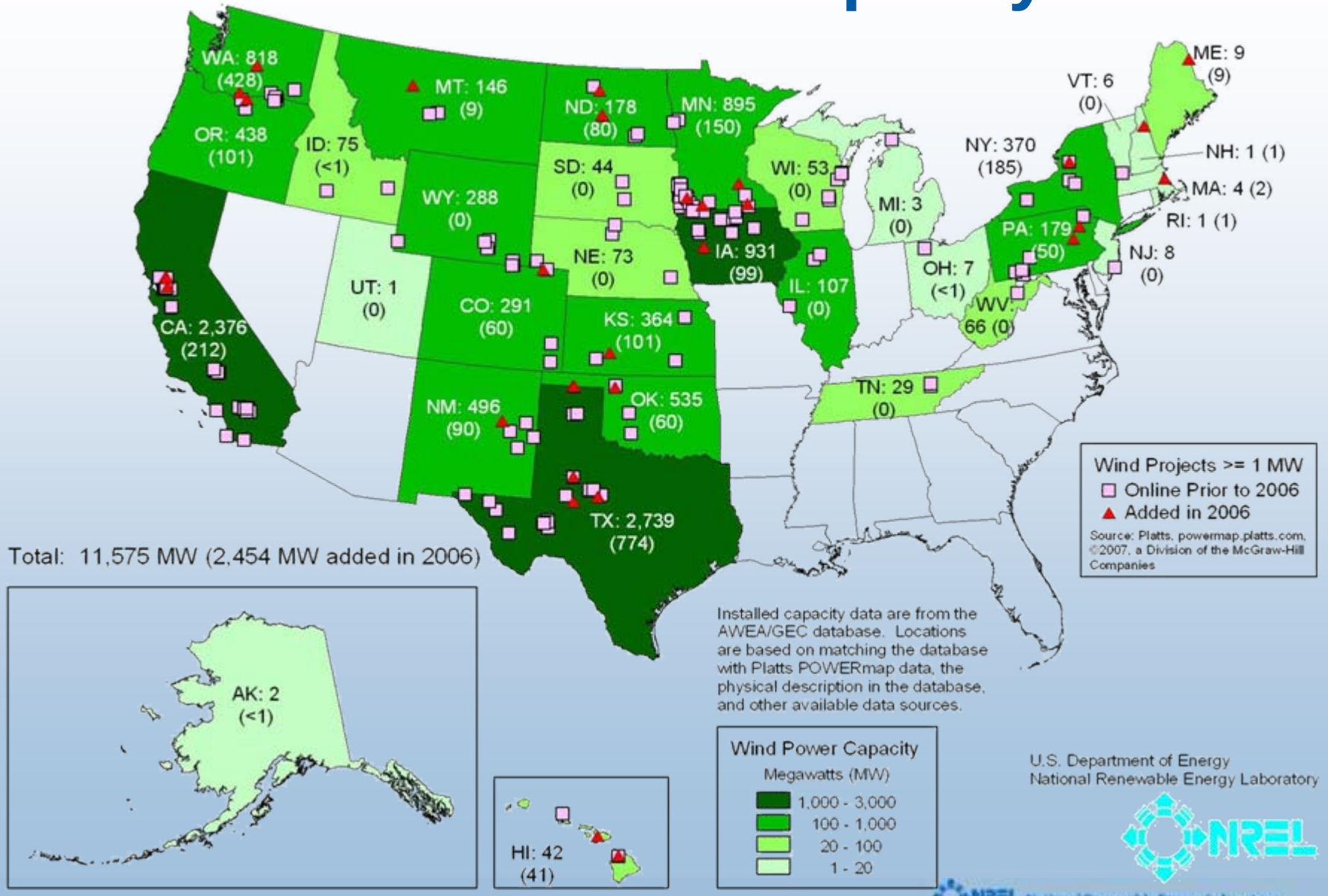
- Improved performance and reliability
- Distributed wind technology
- Advanced rotor development
- Utility grid integration

* With no Production Tax Credit
Updated 1/07, validated 7/07
Source: U.S. Department of Energy, American Wind Energy Association

Evolution of U.S. Commercial Wind Energy



Installed Wind Capacity

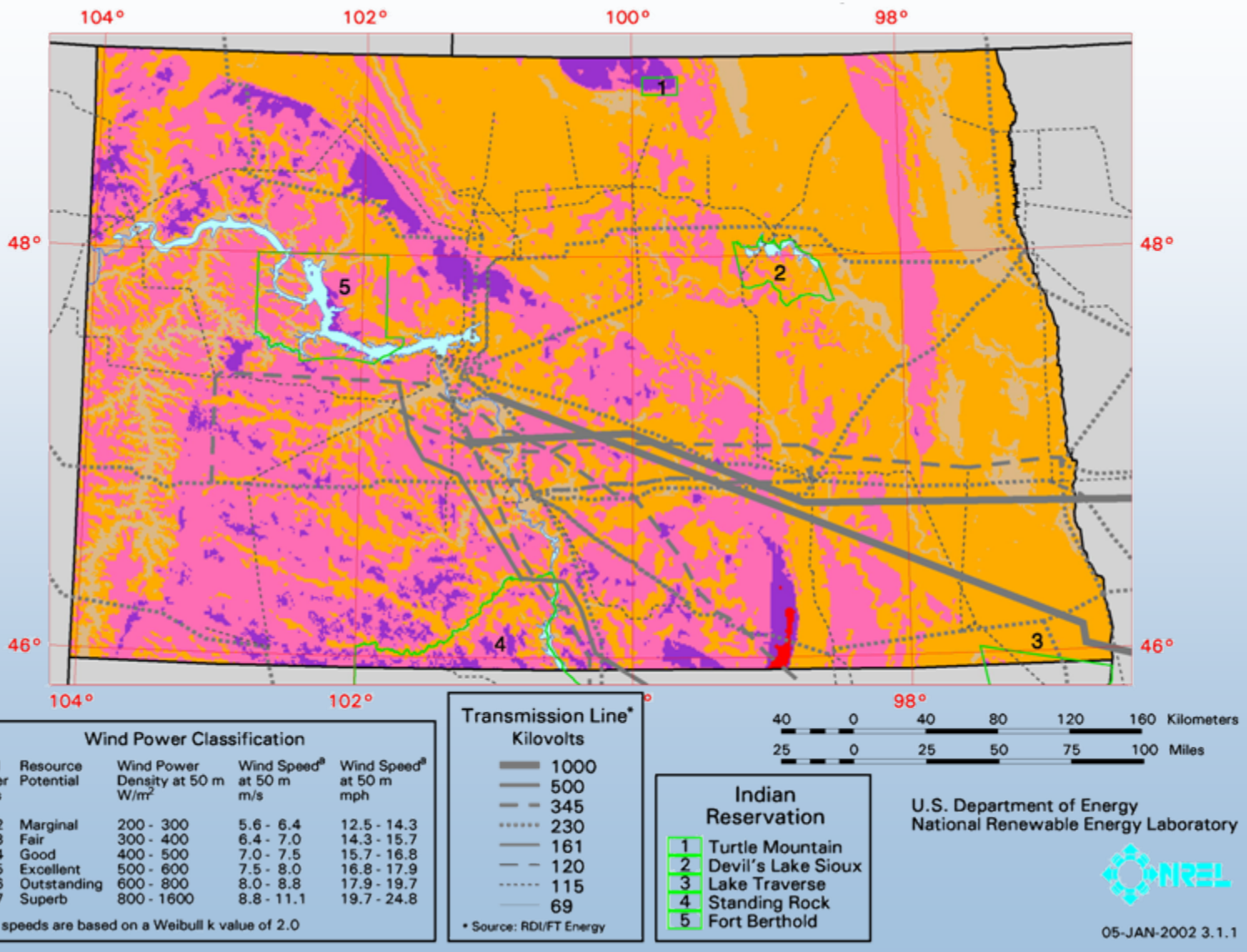


Total: 11,575 MW (2,454 MW added in 2006)

Installed capacity data are from the AWEA/GEC database. Locations are based on matching the database with Platts POWERmap data, the physical description in the database, and other available data sources.

U.S. Department of Energy
National Renewable Energy Laboratory

North Dakota Wind Resources



Solar

Photovoltaics and Concentrating Solar Power

Status in U.S.

PV
- 565 MW
- Cost 18-23¢/kWh

CSP
- 420 MW
- Cost 12¢/kWh

Potential:

PV
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

CSP
8.5¢/kWh by 2010
5-7¢/kWh by 2020

Source: U.S. Department of Energy, IEA, Solar Energy Technologies Program Multi-Year Plan 2007

Updated July 2007

NREL Research Thrusts:

PV
- Partnering with industry
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

CSP
- Next generation solar collectors
- High performance storage

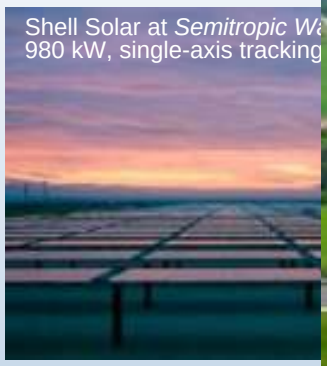
Moving Toward Our Destination


Ridge Vineyards PV Rooftop 65 kW, CA

WorldWater & Power, Irrigation System 267 kW, Seley Ranches, CA


RWE Schott Stillwell Avenue Subway Station, PV Canopy Roof, 250,000 kWh/yr, Brooklyn, NY


Powerlight, Bavarian community 6.750 MW, single-axis tracking Mühlhausen, Germany


Shell Solar at *Semitropic Wa*
980 kW, single-axis tracking


er & Geothermal Energy Co.
stewater Plant, 622 kW,
CA


PowerLight PowerGuard
536 kW, Toyota Motor C


op system,

Geothermal

Today's Status:

- 2,800 MWe installed, 500 MWe new contracts, 3000 MWe under development
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

DOE Cost Goals:

- <5¢/kWh, for typical hydrothermal sites
- 5¢/kWh, for enhanced geothermal systems with mature technology

Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

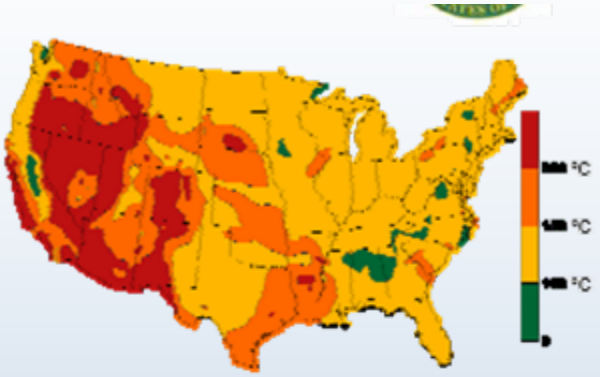
NREL Research Thrusts:

- Analysis to define the technology path to commercialization of Enhanced Geothermal Systems
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

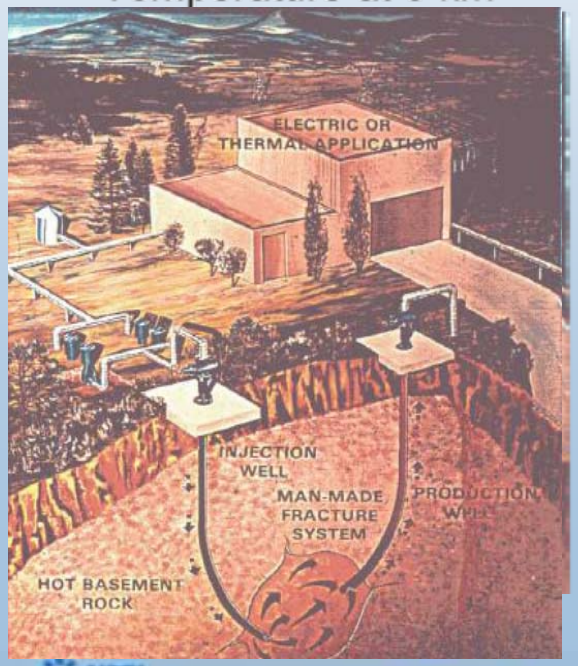
Source: DOE, NREL, 9/07

Enhanced Geothermal Systems (EGS) for Electricity Generation

- **Problem Technology Addresses:** Base load power generation with few or no emissions.
  - **Size of Problem:** Significant shortfall in projected U.S. power generation. Coal may not be able to meet the deficit.
- **Description:** EGS involves engineering a hydrothermal reservoir via fracturing and injection of water to extract heat from the earth.
- **Impact:**
  - Up to 10% (100 GWe) of the current power generation capacity can be from EGS, with potential to install much more.
  - There are essentially no carbon or other gaseous emissions and the geothermal resource is sustainable.
  - The resource exists across the nation.
- **IP Position:** Public domain, with the opportunity for many inventions.
- **Status:**
  - The EGS concept has been shown to be technically feasible at sites in several countries, including the United States.
  - The challenge is to improve EGS technology to ensure economic viability at commercial sites.
  - Field tests are required, starting with improving existing hydrothermal reservoirs, proceeding to expanding existing hydrothermal reservoirs, and ultimately creating reservoirs in challenging conditions.
  - For full-scale EGS development, about $50M to $100M/site.
  - Although the current working fluid is water, there exists the potential for other working fluids such as supercritical carbon dioxide, with attendant sequestration of the carbon. The carbon dioxide working fluid concept is patented and available for licensing, but field testing is required.



Temperature at 6 km



Source: DOE, August 2007

Biopower

Biopower status

- 2006 Capacity – 10.5 GWe
  - 5 GW Pulp and Paper
  - 2 GW Dedicated Biomass
  - 3 GW MSW and Landfill Gas
  - 0.5 GW Cofiring
- 2004 Generation – 68.5 TWh
- Cost – 0.08 – 0.10 USD/kWh

Potential

- Cost – 0.04-0.06 USD kWh (integrated gasification combined cycle)
- 2030 – 160 TWh (net electricity exported to grid from integrated 60 billion gal/yr biorefinery industry)

Biofuels

Current Biofuels status

- Biodiesel – 1.3 billion gallons/yr capacity[1]
- Corn ethanol
  - 121 commercial plants[2]
  - 6.3 billion gal/yr. capacity[2]
  - Additional 6.2 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
  - Projected commercial cost ~$3.50/gge

Key National Goals

- 2012 goal: cellulosic ethanol ~$1.96/gge
- 2017 goal : 35 billion gal alternative fuel – President
- 2022 goal: 36 billion gal renewable fuel – Congress/draft
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

NREL Research Thrusts

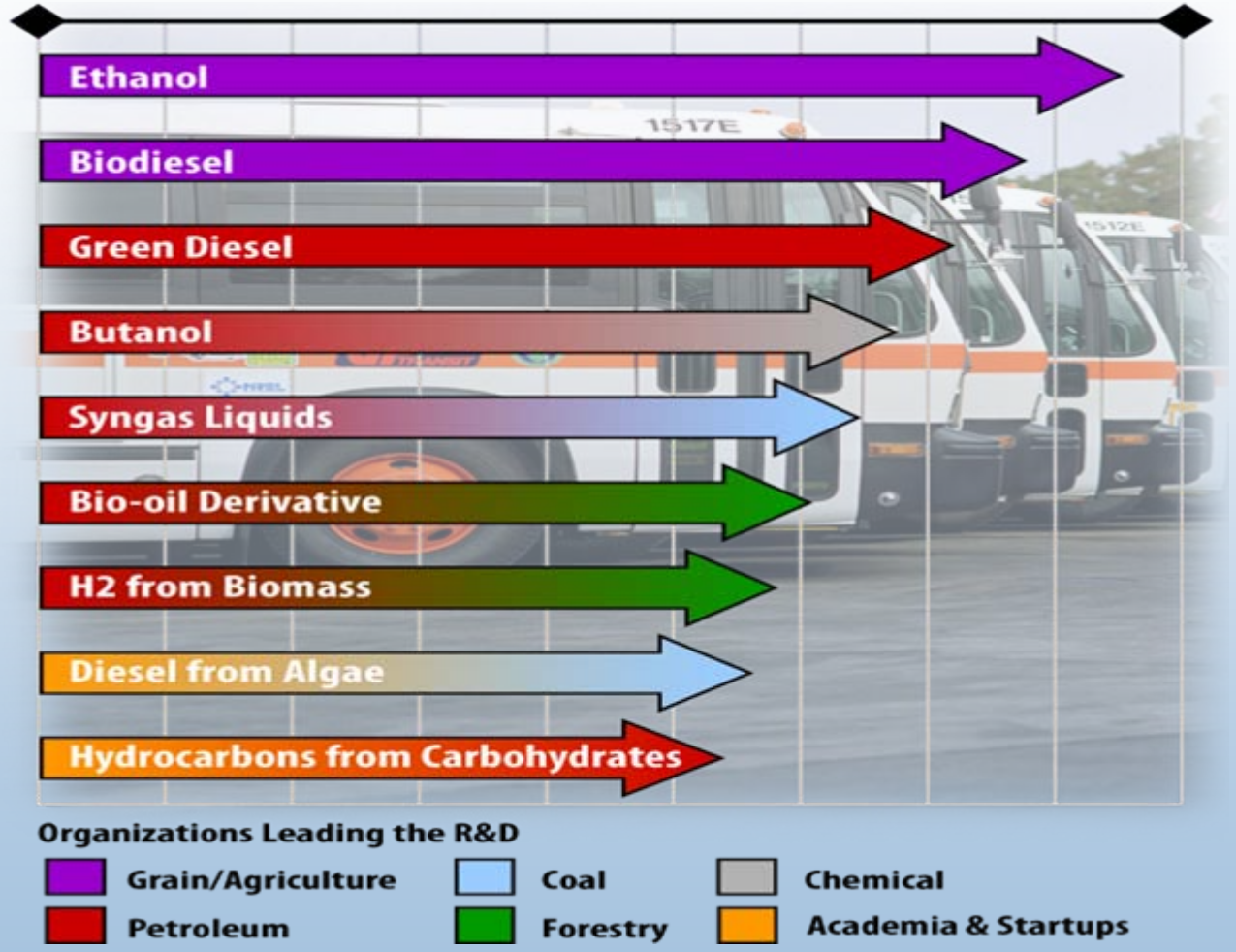
- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops

Updated September 2007

Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, all other information based on DOE and USDA sources

Technology Maturity Pathways

Biofuels



Hydrogen

Status

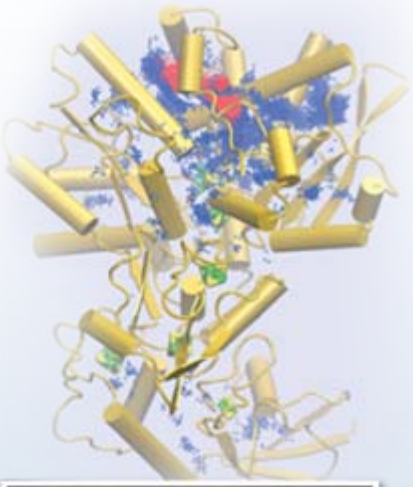
- Working with industry to develop technologies in quantities large enough, and at costs low enough, to compete with traditional energy sources.

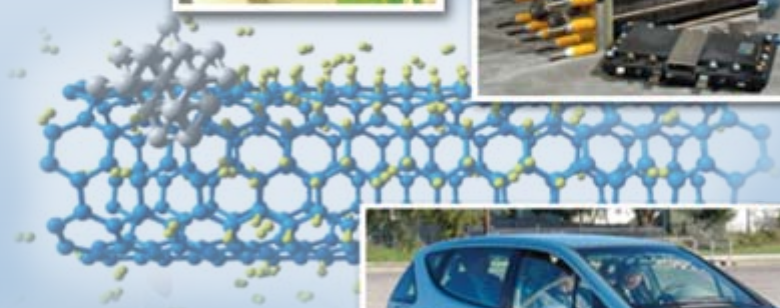
Potential

- Commercially viable hydrogen and fuel cell systems by 2015

NREL Research Thrusts

- Hydrogen production, delivery, storage and manufacturing
- Fuel cells
- Safety, codes, and standards
- H_2-to-Wind – NREL/Xcel Project
  - Maximize wind energy by reducing uncertainty and variability
  - Hydrogen produced through electrolysis





Source: DOE, NREL, 9/07

Plug-In Hybrid Electric Vehicles (PHEV)

Status:
- PHEV-only conversion vehicles available
- OEMS building prototypes
- NREL PHEV Test Bed

NREL Research Thrusts
- Energy storage
- Advanced power electronics
- Vehicle ancillary loads reduction
- Vehicle thermal management
- Utility interconnection
- Vehicle-to-grid

Key Challenges
- Energy storage – life and cost
- Utility impacts
- Vehicle cost
- Recharging locations
- Tailpipe emissions/cold starts
- Cabin heating/cooling
- ~33% put cars in garage

Buildings

Status U.S. Buildings:
- 39% of primary energy
- 71% of electricity
- 38% of carbon emissions

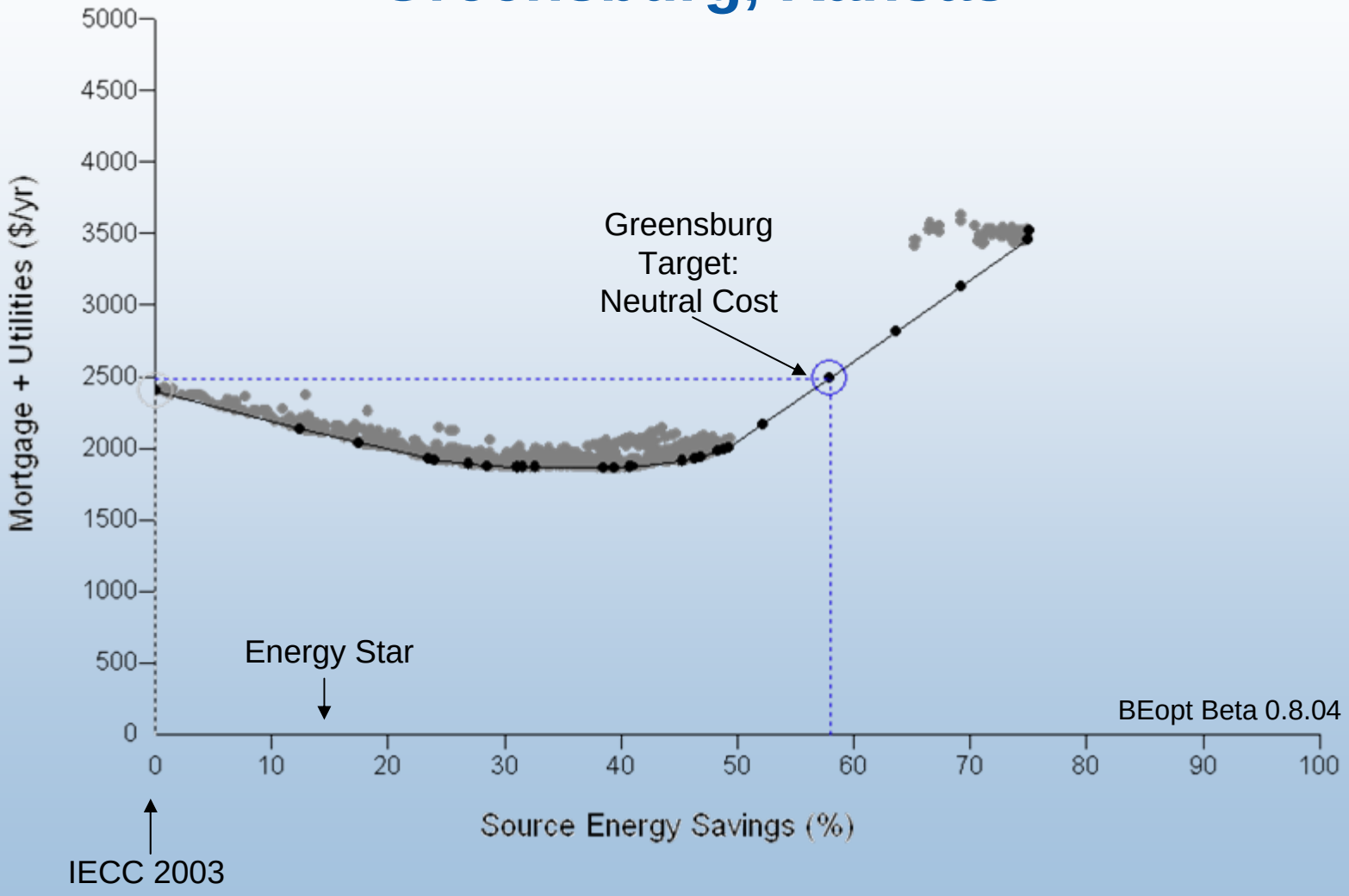
DOE Goal:
- Cost effective, marketable zero energy buildings by 2025
- Value of energy savings exceeds cost of energy features on a cash flow basis

NREL Research Thrusts
- Whole building systems integration of efficiency and renewable features
- Computerized building energy optimization tools
- Building integrated PV

Updated June 2007

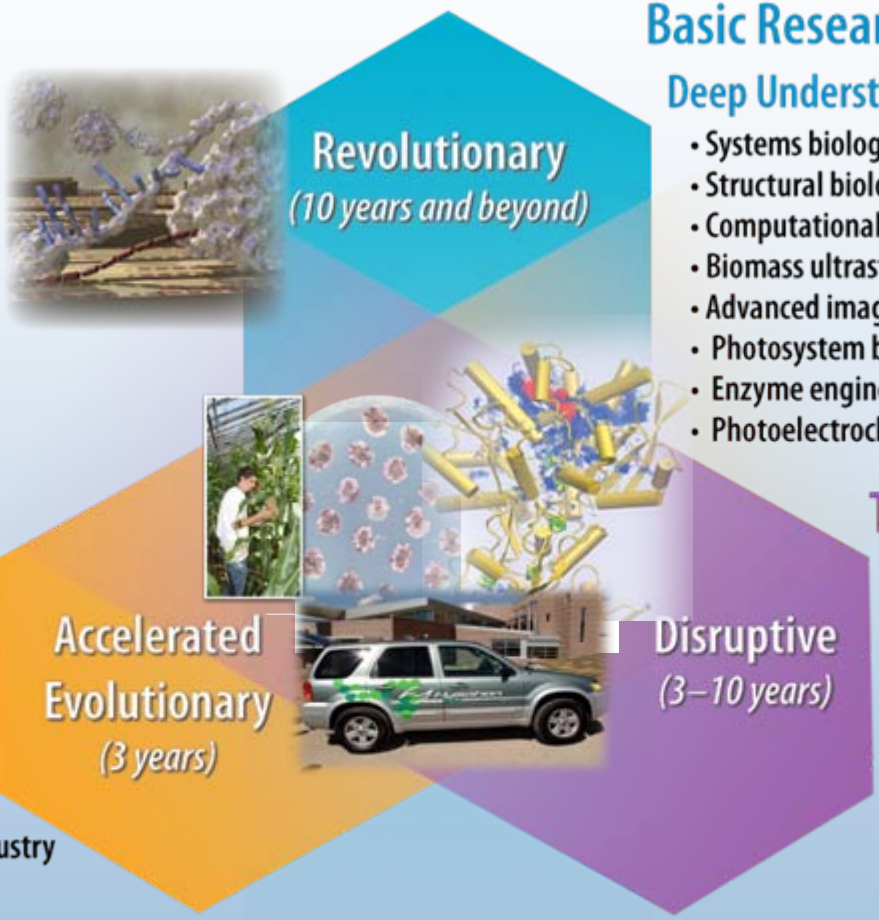
Neutral Cost Point Example

Greensburg, Kansas



(2000 ft2, 2-story, 16% window to floor area ratio, unconditioned basement)

Technology Investment Pathways



Basic Research Driven

Deep Understanding

- Systems biology & HTP
- Structural biology
- Computational science
- Biomass ultrastructure
- Advanced imaging tools
- Photosystem biochemistry
- Enzyme engineering
- Photoelectrochemistry

Industry Driven

Transportation Fuels

- Bioethanol pilot plant
- Technoeconomic analysis
- Performance testing for industry
- Biofuel cells
- Rapid biomass analysis
- Process unit testing

Technology Driven

Translational S&T

- Process consolidation
- Biological hydrogen
- Photoelectrochemical hydrogen
- Biomass pretreatments
- Mapping the plant cell wall
- Plant delignification
- Chemistry of biomass toxins

Source: NREL


The U.S. Department of Energy's
National Renewable Energy Laboratory
www.nrel.gov
Golden, Colorado